A Laboratory Course for Telecommunications Systems Engineering

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Abstract
An integral part of the curriculum in the recently developed Master of Science in Telecommunications Systems program at the University of Oklahoma - Tulsa is a laboratory course. The course is designed to enhance student understanding of fundamental computer networking principles and to expose students to research tools that can be used in carrying out their capstone research projects. Through a series of sequential laboratory modules, students learn to setup and configure simple to complex computer networks and to effectively employ commercial software tools for network design and performance analysis. Near the end of the course, working independently, each student is required to complete a final project that assimilates much of the reinforced and/or newly acquired knowledge and skills. This paper provides a detailed description of the laboratory course and its key project modules.

1. Introduction
The University of Oklahoma - Tulsa offers a Master of Science in Telecommunications Systems under the aegis of the School of Electrical and Computer Engineering. An integral part of the curriculum is the two-credit hour course entitled Telecommunications Laboratory - TCOM 5272. The course is designed to accomplish two objectives: to enhance student understanding of fundamental computer networking principles covered in prerequisite lecture courses and to expose students to research tools that may prove essential for carrying out their capstone research projects. The laboratory course consists of several sequential modules which reinforce and build upon preceding knowledge. These modules train students to setup and configure simple to complex computer networks using Internet Protocol (IP) switches and routers, and to effectively utilize commercial software tools for network design and performance analysis. After completing the laboratory modules, the students are assigned a final project to complete independently. A typical final project encompasses the following steps: build a representative computer network to span multiple cities, configure quality of service to allow for voice traffic, generate data and Voice-Over-IP (VoIP) traffic on the network, capture real-time traffic on the network, analyze the traffic to obtain network performance parameters, and compare the measured parameters with those obtained from prior network simulation. This paper describes the overall outline of the laboratory course, the key project modules, the guidelines for a typical final project, and lessons from the assessment of student learning.
2. Course Outline

*Telecommunications Laboratory* is typically conducted during the eight-week summer semester and meets once per week for three hours. Each session begins with a lecture, followed by time where the instructor is available to students in the lab. Outside of scheduled meeting times, students have unlimited access to the lab so they can complete exercises tied to each laboratory module, as well as work on their final projects near the end of the semester. The final grade is based 70% upon the cumulative grades from the laboratory modules and 30% upon the final project grade. The text used in conjunction with the course is *Networks for Computer Scientists and Engineers* by Youlu Zheng and Shakil Akhtar, Oxford University Press, 2002. In addition, lecture materials are supplemented with selected papers from journals and conference proceedings, as well as articles from the World Wide Web. The topics targeted by the laboratory modules are:

Data Link/Network Layers
- Layer 2/layer 3 addressing
- subnet masking, address resolution
- Media Access
- spanning trees

Network Layers
- routed/non-routed protocols,
- interior/exterior routing protocols
- queuing mechanisms

Transport Layer
- Connectionless Transport: UDP
- Connection-Oriented Transport: TCP
- TCP Congestion Control

Application Layer
- Socket programming basics
- Client/Server
- Peer to Peer
- HTTP, DNS, Telnet, FTP, SMTP

Protocol Analyzers
- Analyze/Visualize data from different layers
- Study throughput, latency and loss
- Analyze SNMP standard MIB data

Simulation
- OPNET
- Layers 3 – 5

3. Laboratory Modules

Each of the laboratory modules are described in the following subsections.

3.1 Basic Switch Configuration, Virtual Local Area Networks (VLANs), and Switch Trunking

The purpose of this module is to familiarize students with the Cisco Catalyst 1900 switch, a key network element that is used in many of the subsequent modules. Students physically connect three switches and then initiate a HyperTerminal connection to each switch, configuring it with a name, IP address, and passwords. Students then configure four VLANs and implement switch trunking to realize the network shown in Figure 1. Finally, students verify network connectivity using *ping* and *telnet* utilities.
3.2 Spanning-Tree Protocol (STP), VLAN Trunking Protocol (VTP), and Inter VLAN Routing

The first objective of this module is to acquaint students with STP. Students first physically connect and configure the two switches to enable the in the basic link shown in Figure 2. Students then enable STP and determine the root switch, investigating priorities and whether a port is forwarding or blocking. Finally, the root bridge and root trunk are enabled.

![Figure 2](image)

Figure 2 – The simple two node link used to investigate STP.

The second objective of this module is to familiarize students with VTP and provide experience with inter VLAN routing. Students physically connect three switches and a Cisco 2600 router,
as shown in Figure 3, then configure VTP to enable the switching environment that is further illustrated. Once connectivity is verified, the router is then configured to allow inter VLAN routing.

![Figure 3](image_url) – The network used to investigate VTP and inter VLAN routing.

### 3.3 Basic Router Configuration

In the previous module, students are required to learn how to configure a router to enable inter VLAN routing. While routers can clearly be used to segment LANs, a more prevalent application for routers is to provide connectivity to Wide Area Networks (WANs), as shown in Figure 4. The primary objective of this module is to provide students with a more in-depth look at the aspects of basic router configuration, especially connection to WANs. The student exercises for this module focus on implementing different configurations for router connections to different network interfaces, e.g., Ethernet and FastEthernet, and subinterfaces for LAN and WAN access.
3.4 Serial Interface Configuration and Static Routing

The primary objective of this module is to introduce students to serial interface configuration as serial interfaces, with implementation of static routing, are widely used to efficiently connect routers to certain WAN services. Students physically connect three switches and three routers in the topology shown in Figure 5. Note that the Data Terminal Element (DTE) and Data Communications Element (DCE) cabling represent a departure from the physical connections shown in previous figures. The students then configure the network elements, including the clock rate and address assignments for static routing. Finally, the students carry out exercises to verify connectivity through the network.

Figure 4 – The simple network used to investigate connection with WANs.

Figure 5 – The network used to investigate serial interface configuration and static routing.
3.5 Routing Information Protocol (RIP) and Access List (ACL)

The manual process of static routing configuration can become unmanageable in large networks. This problem may be alleviated through the use of RIP, which provides dynamic routing. ACLs enable administrators to control access to a network. The objective of this module is to familiarize students with practical implementation of RIP and ACLs. Students create a network very similar to the one shown in Figure 5, with the exceptions being an additional host connected to switch Catalyst_C and an additional network connection between Router C and Catalyst_C. Students carry out a series of actions to configure the routers for RIP, then evaluate connectivity through the network. Subsequently, students perform a number of exercises to investigate the effects of ACL-related functions in a network, culminating with the creation and implementation of a new ACL.

3.6 Equal and Unequal Load Sharing

A router may have more than one connection to a network and thus, load sharing among available paths may provide more efficient bandwidth utilization and higher overall throughput. When two or more paths have equal amounts of available bandwidth, equal load sharing can occur. However, if the available bandwidth varies with path, then unequal load sharing occurs. The objective of this module is to acquaint students with the procedures for configuring routers for balanced and unbalanced load sharing. Students physically connect and configure the network shown in Figure 6. Upon configuration, students perform a variety of exercises to evaluate network throughput in both balanced and unbalanced load sharing conditions.

![Figure 6](image)

Figure 6 – The network used to investigate load sharing.

3.7 Priority Queuing

Voice and video applications require a high Quality of Service (QoS) from the IP networks that provide the supporting bandwidth. Priority queuing is a technique that can be used to achieve high QoS when the aggregate load on a network path exceeds the maximum throughput. The
objective of this module is to introduce students to the steps needed to implement priority queuing on an IP network. Students physically connect and configure the network shown in Figure 7, with the added step of configuring the routers for priority queuing. In this experimental configuration, a traffic injector agent (e.g., NetIQ Chariot) resident on one of the host computers is used to produce the network traffic profiles to evaluate the effect of implementing priority queuing.

Figure 7 – The network used to investigate priority queuing.

3.8 OPNET Simulation
OPNET Technologies, Inc., produces a suite of network modeling and simulation tools that are widely used in the telecommunications and information technology communities and held by many professionals to be the de facto standard. The objective of this module is to familiarize students with the utility of OPNET tools in designing, modeling, and analyzing the performance of networks. Students are introduced through a series of tutorials and then apply OPNET to model and analyze some of the networks in the proceeding modules. The OPNET features of particular interest, as well as sample projects, were discussed by the authors at the 2004 Frontiers in Education Conference².

4. Final Project
To evaluate the students understanding of the overall lab material, a final project encompassing many concepts taught in the individual lab modules is assigned to them. The project is to cost-effectively design a wide area network connecting three local networks at different locations: Tulsa, Oklahoma City and Norman. The site at OKC is connected to Tulsa by an Ethernet link with a data rate of 100 Mbps, but connected to Norman by a serial link with a data rate of 64 kbps. The students are asked to hardwire and configure the network to carry, in addition to data traffic, a minimum of five VoIP conversations between Norman and Tulsa. A careful analysis of the network latency and packet loss performance is needed to carry out the objectives of the
design project. The analysis is accomplished by students using the physical network they build and confirmed with the results obtained from the network simulation. A list of major steps performed by students to accomplish the project is summarized as follows:

- Physically connect the sites,
- Assign IP addresses to the routers and switches,
- Generate network background traffic that reasonably represents data traffic,
- Generate VoIP traffic with different Codecs from Tulsa to Norman or vice versa,
- Capture network traffic at Tulsa and Norman sites,
- Analyze the network latency and packet loss of voice traffic,
- Upgrade link bandwidths to cost-effectively carry a minimum of five VoIP conversations, and
- Confirm the analysis obtained from the network with those obtained from the OPNET simulation.

Figure 8 shows an example of a wide area network completed by a student.

5. Assessment of Student Learning
A simplified assessment in which the students provided written feedback is carried out at the end of the semester. The students responded positively to the integration of “hands-on” experiments with the simulation and software analysis. However, many students complained about the long lab hours required to perform the lab assignments. Collection of quantitative assessment data is ongoing, but is inadequate to report at this time.
6. Conclusion
This paper describes the Telecommunications Laboratory course, an integral component in the Telecommunications Systems curriculum at The University of Oklahoma – Tulsa. Students complete a series of laboratory modules that enhance student understanding of fundamental computer networking principles covered in prerequisite lecture courses and to expose students to research tools that may prove essential for carrying out their capstone research projects. Instructor evaluation of student performance and qualitative student feedback indicates that course objectives are being met.

Bibliographic Information


Biographical Information

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